THE IMPACT OF PRIORITY CONSISTENCY
ON THE PERFORMANCE OF A JOB SHOP

THESIS

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Presented to the Faculty of the Graduate School of Logistics

and Acquisition Management of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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September 1995

Acknowledgments

First and foremost, I would like to thank my family, Christi and Brynn, for their incredible patience and understanding during the 15 months it took to complete this thesis. Without their continuous support, I might have never made it through this process.

I would also like to express my sincere appreciation to my thesis advisor, Lt Col Jacob Simons. Throughout this process, he not only advised me on the specific issues addressed in this research, but also provided a broader understanding of academic research, its applications, and its limitations. His truly compassionate attitude and unique perspectives made this research process enlightening and enjoyable.

I would also like to thank the various AFIT faculty and staff that helped me with this project in one way or another. Thanks to Major Wendell Simpson for acting as my reader and providing helpful suggestions throughout. Thanks to Major Mark Kraus and Michael Rader for their time and efforts in providing me with what seemed like continuous computer resource support. (They are probably more happy than I am that the process is finished). I would also like to thank Major Kraus for his insights on computer simulation and experimental design.

Finally, I would like to thank the fellow members of the GLM 95S class. Their unorthodox study habits, witty attitudes, and unusual sense of humor helped me maintain perspective on the graduate learning process. Without their friendship and encouragement, the last 15 months would have seemed like a lifetime. Thanks guys.

Ken Bailey

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Abstract

This study introduces the construct of consistency to production and operations management research. As a job passes through a job shop, its priority may or may not remain consistent relative to the other jobs in the system. A new classification of priority rules is introduced. Consistent priority rules are those that maintain a job's priority relative to all other jobs throughout the system. Inconsistent priority rules are those that allow a job's relative priority to change as it moves from queue to queue. This study is a preliminary investigation to determine the effect on performance from the use of consistent and inconsistent rules. A simulation experiment was conducted using a full two-factorial repeated measures design with the two main factors being consistency and priority rule operating characteristic. Data was collected in terms of flow time, tardiness, and the average age of the jobs in the shop. Results showed that there was a significant interaction between the operating characteristic and the consistency of a priority rule for all mean performance measures. In all cases where the differences within an operating characteristic were significant, the inconsistent priority rules performed better than their consistent counterparts. This was because the consistent priority rules tended to eliminate priority advantages gained through the use of inconsistent priority rules. Overall, this suggests that in systems that can be modeled as job shops, local management of prioritization schemes will produce better performance than a "systems perspective."

THE IMPACT OF PRIORITY CONSISTENCY

ON THE PERFORMANCE OF A JOB SHOP

I. Introduction

General Issue

Scheduling is an important function of production and operations management (POM). Scheduling is made up of different elements: order release, sequencing, dispatching, and due date setting. (Ahmed and Fisher, 1992:633) Each of these elements has received a vast amount of attention in POM research. In particular, sequencing and dispatching have been shown to be of great importance in improving the performance of various processes.

Sequencing is the prioritizing of a set of jobs in a queue based on some decision rule to determine the order in which they will be processed. Dispatching is simply the selection of the next job from a queue of waiting jobs based on some priority rule. The establishment of these priority rules and the decision of which priority rule to use to obtain optimum performance have received a lot of attention in POM research. Previous studies have assessed the impact of various priority rules on the performance of many production processes under a variety of conditions.

One of the more common processes modeled in POM research is the job shop. Generally, job shop production systems consist of jobs being processed through some number of workcenters (machines) where the routing that any particular job takes is not necessarily the same as other jobs. For each workcenter, there exists a queue in which jobs wait to processed. When a machine becomes available, the next job to be processed is selected from the appropriate queue based on some priority rule.

Job shop scheduling is of considerable importance because many productive processes can be modeled as job shops (Kanet and Hayya, 1982:167). In particular, many Air Force and Department of Defense (DOD) processes can be modeled as jobs shops. Some examples of such processes include repairing aircraft or components in a maintenance organization, in- or out-processing of personnel or equipment for a deployment, and processing patients through a hospital.

By modeling these production processes as jobs shops, managers of these processes can make use of optimal dispatching strategies, or prioritization schemes, that have been shown to result in improvements against desired performance measures. The choice of the prioritization scheme implemented directly affects the performance of the shop because the priority rules used establish when work starts for each job. Proper selection of priority rules can yield improved performance of the system in terms of some desired performance measure (Conway and others, 1967:2).

This study addresses a potential guideline for production managers in selecting the type of priority rules to implement in a "job shop-like" system in order to optimize a desired performance measure.

Specific Problem

In a job shop, as jobs wait to be processed at a workcenter, they possess a priority relative to the other jobs waiting for the same resource. Assigned priorities are established based on the priority rule used at that particular workcenter. These rules determine relative priorities based on some characteristic of the jobs. Thus, priority rules can be said to have an operating characteristic which is defined as the basis of information used to determine the relative priority of a job. For example, one of the most common priority rules is First Come, First Served (FCFS). The operating characteristic of this rule is the arrival of the job. Thus, FCFS is arrival-based. Similarly, the Shortest Processing Time

(SPT) rule is processing time-based, and the Earliest Due Date (EDD) rule is due date-based. See Appendix A for a description of the above listed priority rules.

If one looks at a job shop operation, it is conceivable that as a job progresses through the shop, its priority relative to the other jobs in the system can change from one workcenter to the next. Even if the same priority rule were used at each workcenter, the nature of some priority rules allow a job's relative priority to change as it passes through the system.

Based on the above observation, we can introduce a new classification of simple priority rules. A consistent priority rule is one that causes a job to maintain the same priority relative to other jobs throughout the entire process. For example, if Job A has a higher priority than Job B at one workcenter, a consistent priority rule will cause Job A to maintain a higher priority than Job B every time they occupy the same queue in the shop.

Conversely, an inconsistent priority rule is one that allows a job to have different priorities at different workcenters relative to the other jobs in the system. For example, if Job A has a higher priority than Job B at one workcenter, it may or may not have a higher priority at subsequent workcenters when an inconsistent priority is used.

The primary objective of this research is to answer the following question: What is the impact on the performance of a job shop if the jobs' relative priorities are consistent across queues versus the same system when the jobs' relative priorities are allowed to change as they pass from one queue to the next? Although comparisons of priority rules conducted in previous research have included both consistent and inconsistent rules, the construct of consistency may have been a confounded factor that has not been previously isolated to assess its contribution to the performance of the system.

Investigative Questions

In order to meet the broader objective of this research described above, the following investigative questions were established to guide the focus of the study:

1) Is there any previous research on the concept of consistency of priority rules? If not, are there any trends in existing studies that make comparisons between consistent and inconsistent priority rules?

2) Do consistent priority rules generally perform better than inconsistent rules (or vice versa) regardless of the operating characteristic? Do consistent/inconsistent priority rules perform better against certain performance measures?

3) Does the effect of the consistency depend on the operating characteristic of a priority rule?

4) Are there other interesting observations that can be made based on a comparison of consistent and inconsistent priority rules?

Design

In order to answer the first investigative question, I will conduct a literature review and compare the results of a sample of existing studies that have made a comparison of consistent and inconsistent simple priority rules. To answer the second and third investigative questions, I will conduct a simulation experiment to provide data for a full 2-factorial experimental design. To answer the fourth question, I will look at the results of the data analysis for any interesting or unexpected results.

Scope

This study will focus on an unconstrained job shop under steady-state conditions. Each workcenter within the job shop will use the same priority rule. The performance of the job shop will be measured in terms commonly used in scheduling research.

The simulation software used in this experiment is FACTOR/AIM developed by the reputable Pritsker Corporation. This software was chosen for a couple of reasons.

First, FACTOR/AIM has production management applications in both research and practice. It was design to be used by practitioners wanting to model their own processes in order to assess the impact of changes to the system. Consequently, it has a user-friendly graphical interface, and many built-in functions and resources that are commonly found in practice. Second, since it was developed by the Pritsker Corporation, it has the same sound random number generator as the Simulation Language for Alternative Modeling (SLAM), which has been used extensively in POM research.

Assumptions

For this experiment, a number of assumptions were deemed necessary. The following is a list of those assumptions along with a brief justification for them:

1) In order to maintain the integrity of the queue disciplines, jobs cannot pre-empt other jobs in the queue.

2) The machines that make up the workcenters cannot breakdown since such an occurrence would have no bearing on the objectives of the experiment.

3) Set up times are included in the processing times since isolating them would have no bearing on the objectives of the experiment.

4) The transit time between workcenters is negligible since including them would not change the relative performance of any priority rule.

5) There are no constraints on labor, tools, or materials to ensure that all jobs are subject to the same shop conditions throughout the experiment.

6) There are is no alternate routing, or balking, since such occurrences could interfere with the integrity of the queue disciplines.

7) Each queue has an unlimited capacity to avoid blocking.

Summary

This chapter established the focus of this research effort and presented some preliminary information necessary for answering the investigative questions. In Chapter II, I will present the results of the literature review and attempt to answer the first investigative question. In Chapter III, I will describe the methodology employed, to include delineating each experimental factor and controlled variable. I will also describe the job shop model, and the experimental design employed for statistical analysis of the simulation output. In Chapter IV, I will present a discussion of the data generated by the simulation to include an assessment of how well it meets the underlying assumptions of the analysis. I will report the results of the statistical analysis, and discuss the more interesting findings. Finally, in Chapter V, I will provide some overall conclusions based on the experimental results and suggest some extensions of this research for the future.

II. Literature Review

Introduction

In this chapter, I will describe the results of a review of previous research related to the topic of this thesis. First, I will describe the approach taken toward this review and explain the rationale behind that approach. Then, I will present a classification of priority rules that will help describe the main factors involved in the literature review and the experimental design discussed in Chapter III. Finally, I will discuss the results of some previous studies and how they relate to this research.

Approach

The traditional approach of the literature review is to survey previous research to find studies that directly or indirectly relate to the topic of interest. This is done for two reasons. First, it provides the researcher with the most current developments and conclusions made on the particular problem being addressed. Second, it gives the researcher a starting point from which to extend "to a more complex case in the same problem domain" (Simons and Khumawala, 1993:168).

This traditional approach appeared to be inappropriate for this research simply because the notion of consistency in prioritization schemes has not been previously addressed in POM research. An extensive review of the literature did not reveal a single POM study that isolated this construct of consistency with respect to priority rules in production systems. Therefore, a different approach was adopted stemming from the first investigative question described in Chapter I.

There are a vast number of papers that address priority rules in job shop environments. A review will not be presented here since excellent overviews of those studies can be found in survey papers such as Ramasesh, 1990; Cheng and Gupta, 1989;

Baker, 1984; Sen and Gupta, 1984; Blackstone, et. al., 1982; Graves, 1981; Panwalker and Iskander, 1977; Day and Hottenstein, 1970; Spinner, 1968; and Moore and Wilson, 1967. However, among those studies that address priority rule performance, there are a handful of researchers who, in the course of achieving their research objectives, have provided comparisons between consistent and inconsistent priority rules.

As a result of the existence of such research, the approach of this literature review is to look at a few of those studies to determine if there are any a priori expectations that can be made regarding the impact on performance from consistency in priority rules. Before I discuss those results, it is necessary to present a classification of priority rules that will be helpful in describing the factors involved this investigation.

Categories of Priority Rules

Priority rules used in determining the order in which jobs will be dispatched from a queue in any type of shop can be placed into five categories in terms of their various operating characteristics. These categories are listed in Table 2-1.

Table 2-1

Operating Characteristics of Priority Rules

Arrival-based rules:	Priority is determined as some function of the time the job entered the system/queue.
Time-based rules:	Priority is determined as some function of the processing time of the job.
Due date-based rules:	Priority is determined as some function of the due date of the job/operation.
Value-based rules:	Priority is determined as some function of the value of the job/operation
Combination rules:	Priority is determined as some function of one or more of the above categories.

(Ramasesh, 1990:48)

In Chapter I, a new classification of priority rules in terms of consistency was introduced. Looking at the first three operating characteristics in Table 2-1, we can show both an inconsistent and consistent version for each category of operating characteristic. A matrix showing these combinations is presented in Table 2-2. Please refer to Appendix A for a description of these priority rules.

Table 2-2

Summary of Priority Rules

Operating Characteristic	Consistent Version	Inconsistent Version
Arrival-based:	First-in-system, first-served (FISFS)	First-come, first-served (FCFS)
Time-based:	Shortest Total Processing Time (STPT)	Shortest Processing Time (SPT)
Due date-based:	Earliest Job Due Date (EDD)	Earliest Operation Due Date (ODD)

Using the priority rules shown in Table 2-2, it should be easier to see the notion of consistency. The consistent version of the arrival-based rules (FISFS) gives priority to the jobs that arrived to the shop first. If Job A arrives to the shop 5 minutes before Job B, Job A will always have priority over Job B. On the other hand, the inconsistent arrival-based rule gives priority to the job that arrived to a particular queue first. Therefore, even if Job A arrived to the shop first, Job B may have arrived to the current queue first, and therefore, would have priority over Job A for that workcenter. This may not necessarily be true for other workcenters since the relative priority assigned to jobs in those queues is dependent upon their arrival to that queue. This same contrast can also be seen for the processing time and due date-based rules.

The matrix shown in Table 2-2 will provide the basis for the experimental design described in Chapter III. Thus, the six priority rules shown are the focus of the investigation into the literature. In other words, what is of prime interest are those studies that have made comparisons between consistent and inconsistent versions of arrival-based, processing time-based, and/or due date-based rules (i.e. FISFS versus FCFS, STPT versus SPT, and EDD versus ODD). In the next section, a summary of the results of that inquiry will be presented.

Findings

One of the first simulation experiments to compare a variety of priority rules was performed by R. W. Conway for the Rand Corporation (Conway, 1964). The objective of this experiment was to determine which priority rules, out of 92, produced the best performance in terms of a wide range of performance measures. From this experiment, Conway published two subsequent papers to show the "better" priority rules in terms of Work-In-Process (WIP) (Conway, March-April 1965) and due date performance (Conway, July-August 1965). Although he did not explicitly recognize it as such, his experiment made direct comparisons between consistent and inconsistent priority rules of the same operating characteristic.

In Conway's paper in which he measured performance in terms of Work-In-Process (March-April, 1965), FISFS performed better than FCFS for both mean and variance of WIP and flow time. This supports the idea that consistent rules perform better than inconsistent. However, Conway also reported that SPT performed better than STPT in terms of both mean and variance of WIP and flow time. This result is just the opposite of the arrival-based rules, suggesting the presence of an interaction effect between the operating characteristic and the consistency of priority rules. (Conway did not present the performance results of ODD and EDD in this paper).

In Conway's second paper, he focused on due-date performance (July-August 1965). These results again showed better performance of FISFS over FCFS in terms of mean lateness. However, the results also showed that FCFS did better than FISFS in terms of variance of lateness. In this paper, Conway did compare EDD and ODD and reported that EDD outperformed ODD against mean and variance of both flow time and lateness. These results again suggest an interaction effect between operating characteristic and consistency, but also suggest that the interaction effect may not be consistent across all performance measures. This point will be addressed further in Chapter III.

Another study to make a comparison of consistent and inconsistent due date-based rules was done by Kanet and Hayya (1982). They compared ODD and EDD to see which performed better with respect to due date performance. The results of their study showed that ODD performed better than EDD in terms of mean lateness, fraction of tardy jobs, and maximum job tardiness. In addition, they also showed that the variance of lateness was smaller with ODD than with EDD.

With respect to the relative performance of ODD to EDD, the results of Kanet and Hayya (1982) are contradictory to those of Conway (July-August 1965). Kanet and Hayya attribute these contradictions to the different methods of calculating the operational due dates. Conway set the operational due dates by first subtracting the arrival time from the job's overall due date (defined as the job's overall allowance). Then, he divided the overall allowance by the total number of operations of the job to obtain operational allowances. Each operational allowance was added to the completion time of the previous job (or arrival time for the first job) to obtain the specific time that each job's operation was due.

Kanet and Hayya calculated the operational due dates by multiplying each processing time by a constant factor, then adding this allowance to the due date of the previous operation (or the arrival time for the first operation). They used this method as

opposed to Conway's because it was shown by Orkin (1966) to be the best method for computing a job's allowance.

The research conducted by Conway, and Kanet and Hayya, represent the clearest comparisons of consistent and inconsistent priority rules of the same operating characteristic. There are a number of other studies that make such comparisons. However, the objective of most of these other studies was to investigate the impact of other intervening variables on the performance of a job shop. As such, the information drawn from those studies with respect to consistency versus inconsistency may not have a great degree of significance because of the potential confounding effects of the other intervening variables.

Having said that, it is interesting to look at the various research from a macro level. Tables 2-3 through 2-7 are summaries of studies that have made comparisons between consistent and inconsistent priority rules, but are not restricted to those comparisons within the same operating characteristic. The purpose of these tables is to try to see whether there are any visible patterns of performance from consistent or inconsistent priority rules. The research efforts listed in these tables have different objectives and experimental factors. If there are any visible patterns, we may be able to make some general a priori statements about the significance of the consistency factor.

Each table represents a different performance measure. There is one column for consistent priority rules and one for inconsistent priority rules. Similarly, there is one row of cells for those studies that made comparisons within the same operating characteristic (like Conway and Kanet and Hayya), and another row of cells for those that made comparisons across operating characteristics. An example of the latter would be a comparison of SPT to EDD. As each study was reviewed, the researcher's name was placed in the cell that represented which priority rule performed better. For example, if an inconsistent rule was compared to a consistent rule of the same operating characteristic, and the inconsistent rule performed better, the researcher's name was placed in the upper

left cell of the table that represents the intersection of inconsistent rules (because it performed better), and comparisons within the same operating characteristic.

As mentioned before, the experimental objectives of the studies reviewed varied, and as a result, the contributing factors differed from one study to the next. However, looking at Tables 2-3 through 2-7, it is readily apparent that the type of job shop model used has an impact on the relative performance of consistent and inconsistent priority rules. More specifically, in Tables 2-3, 2-4, and 2-5, the consistent rules perform better than the inconsistent rules in assembly shops. An assembly shop is a job shop that incorporates levels of assembly such that a job is not finished until all of its associated components have completed their routing through the shop and have been assembled into the final product.

Table 2-3

Comparisons of Mean Flow Time

	Consistent	**Inconsistent**
Compares Same Operating Characteristic	Conway (Jul/Aug 1965) Rachamandugu, et al (1993) - FISFS *Sculli (1987)* *Goodwin and Goodwin (1982)* *Goodwin and Weeks (1986)*	Kanet and Hayya (1982) Rachamandugu, et al (1993) - ODD
Compares Different Operating Characteristics	*Russel and Taylor (1985)* *Fry, Philipoom, and Markland (1988)*	Elvers and Treleven (1985) Philipoom and Fry (1990) Fryer (1975)

Note: *Italics* denotes studies with Assembly Shops

Table 2-4

Comparisons of Flow Time Variances

	Consistent	Inconsistent
Compares Same Operating Characteristic	Conway (Jul/Aug 1965) Nelson (1967) *Sculli (1987)* *Maxwell (1969)*	Kanet and Hayya (1982)
Compares Different Operating Characteristics	Fryer (1975)	

Note: *Italics* denotes studies with Assembly Shops

Table 2-5

Comparisons of Mean Tardiness

	Consistent	Inconsistent
Compares Same Operating Characteristic	Conway (Jul/Aug 1965) *Sculli (1987)* *Maxwell (1969)* *Goodwin and Weeks (1986)*	Kanet and Hayya (1982)
Compares Different Operating Characteristics	Elvers and Treleven (1985) Ahmed and Fisher (1992) Ragatz and Mabert (1988) Vespalainen and Morton (1987) *Russel and Taylor (1985)* *Fry, Philipoom, and Markland (1988)*	Philipoom and Fry (1990)

Note: *Italics* denotes studies with Assembly Shops

Table 2-6

Comparisons of Tardiness Variance

	Consistent	Inconsistent
Compares Same Operating Characteristic	*Sculli (1987)*	Kanet and Hayya (1982)

Note: *Italics* denotes studies with Assembly Shops

Table 2-7

Comparisons of Mean Work-In-Process

	Consistent	Inconsistent
Compares Same Operating Characteristic	Conway (Mar/Apr 1965) - FISFS	Conway (Mar/Apr 1965) - SPT *Goodwin and Weeks (1986)*
Compares Different Operating Characteristics		Wilbrecht and Prescott (1969)

Note: *Italics* denotes studies with Assembly Shops

In his paper, Sculli (1987) suggests that those rules that tend to do better in assembly shops are those that coordinate the completion time of parts of the same job. According to Sculli, "a rule tends to coordinate if it assigns the same, or nearly the same, priority values to different operation of the same job" (Sculli, 1987:51). This description is remarkably similar to the definition of a consistent rule presented in Chapter I. Based on this similarity, one would expect consistent rules to perform better than their inconsistent counterparts in Assembly Shops.

When looking at the studies that compared consistent rules with inconsistent rules of different operating characteristics (i.e. SPT versus EDD), the only apparent patterns are in Tables 2-3 and 2-5. In Table 2-3, the inconsistent rules tend to perform better in the job shops (not the assembly shops). However, this is what would be expected since the performance measure of interest is mean flow time and the inconsistent rule used in each study listed was the SPT which has been shown to be the best in minimizing mean flow time (Ramasesh, 1990:54).

Most of the studies listed in Table 2-5 made comparisons between EDD and SPT against tardiness measures. In each study listed, EDD outperformed SPT . However, it is also important to note that each researcher was addressing a different issue involving a variety of other intervening variables. Thus, it is nearly impossible to draw any general conclusions from these comparisons because there is no way of knowing whether the performance of a particular rule is attributed to its consistency, or its operating characteristic, or some other variable.

Summary

In this chapter, the results of the literature review were presented based on a slightly unconventional approach. From this review, it can be seen that consistency is potentially a significant factor that has previously been ignored. In addition, there is evidence that there is significant interaction between the consistency of a priority rule and its operating characteristic, and that the relative performance and interaction effect is probably different across various performance measures.

This review also suggests that consistent rules would tend to perform well in assembly shops where job coordination is desirable. In particular, the study by Sculli (1987) provides a strong indication of the impact of consistency on the performance of an assembly shop. In that study, he did not explicitly categorize priority rules as consistent or

inconsistent, but instead used similar classifications of "coordinating" and "non-coordinating" priority rules. Although he used only one non-coordinating priority rule (SPT), its performance was worse than all of the coordinating rules against each of the performance measures he looked at. Unfortunately, Sculli fell short of making generalized conclusions regarding the relative performance of coordinating and non-coordinating priority rules in assembly shops, but suggests this as a topic requiring a "large amount of research" (Sculli, 1987:57).

The classification of priority rules presented early in this chapter was useful in defining the scope of the literature review. This classification will be of great importance in the next chapter as well where I will describe the methodology employed in this experiment to include the key experimental factors, background variables, shop model, and method of analysis.

III. Methodology

Introduction

In this chapter, I will describe the methodology used to assess the impact of priority consistency on the performance of a hypothetical job shop. I will begin by describing the method for collecting data that will subsequently be used in the experimental design. Then, I will describe the experimental design employed to include a summary of the primary experimental factors and their corresponding levels. I will also discuss the background variables that could have had an impact on the results had they not been controlled.

I will describe the job shop model used in this experiment and include the reason why it was chosen. I will then describe the conditions under which the job shop will operate and discuss the measures by which the performance of the shop will be evaluated. Then, I will describe the type of analysis that will be used to obtain the results reported in Chapter IV. This will include a description of the appropriate mathematical model, a delineation of the hypotheses tested, and a discussion of the underlying assumptions. Finally, I will present a brief discussion of what I expect the results will show with respect to each performance measure.

Data Collection

Ideally, it would be desirable to take a real-world job shop and manipulate it to achieve the conditions necessary for this experiment. However, this would be impossible for several reasons. First, in order to avoid the confounding effects of intervening variables, we would need to be able to control them. There is no way to guarantee that all potential intervening variables were controlled in the real world. Second, for reasons that will be discussed later, it is necessary that the experimental conditions be replicable. With

all of the potential intervening variables and the amount of time required, one can easily see that replication of the experimental conditions would be virtually impossible. Third, in a real shop, it would take an inordinate amount of time to collect enough data to draw significant conclusions. Even if both of the previous conditions could be met, it would be virtually impossible to find a job shop manager that would allow such a disruption in his or her operation for a long period of time merely for this experiment.

In order to achieve the necessary conditions described above, I concluded that computer simulation was the most appropriate method for collecting the data. Using computer simulation, I am able to control all potential intervening variables, easily replicate the experimental conditions, and generate adequate sample sizes for analysis in a reasonable amount of time without any major disruption to the real world.

Experimental Design

A designed experiment is "a test or series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response" (Montgomery, 1991:1). This research employs a two-factor factorial design with repeated measures. Before I justify selecting this type of design, it is appropriate to describe the main experimental factors.

Main Factors. The main factors of this experiment were chosen based on investigative questions 2 and 3. These factors were selected from a longer list of input variables. Those variables not selected to be main factors were designated background variables and will be discussed later.

Experimental Factor 1: Consistency. The primary focus of this research is to assess the impact of priority consistency on the performance of a job shop. Therefore, the first experimental factor was chosen as a direct result of investigative question 2. Obviously, this factor deals with the consistency of priority rules and exists at

2 levels: consistent and inconsistent. The response of the job shop process as a result of changing this factor from one level to the other will provide the necessary information for answering investigative question 2.

Experimental Factor 2: Operating Characteristic. As shown in Chapter II, priority rules have traditionally been classified on the basis of the information or job characteristic necessary to calculate the relative priorities of jobs (referred to in Chapter 2 as the operating characteristic). In order to assess the overall impact of consistency, it is necessary to examine its effect over a range of priority rule operating characteristics. Thus, a logical choice for a second factor is the operating characteristic of priority rules. From Table 2-1, one can see that this factor can potentially exist at five levels. However, this research will only focus on the first three levels of operating characteristic: arrival-based rules, processing time-based rules, and due date-based rules. The existence of this factor will provide the necessary information to answer the third investigative question.

Background Variables. Those input variables that may have an impact on the results, but were not selected to be main factors were designated as background variables. To control their effects on the experiment, all of the background variables in this study were held constant. A summary of each background variable follows.

Shop Type. Even though the literature review in Chapter II suggests that the effects of shop type are significant, this variable was not treated as an experimental factor. This is because in order to achieve generalizable results, many different types of shops would need to be included resulting in an extremely complex experimental design. Since this is an initial investigation into the effects of consistency, simplicity was considered more important. In addition, a complementary thesis effort was undertaken on a different shop type (Gismondi, 1995). Therefore, a hypothetical job shop was chosen as the shop type for this experiment.

Shop Utilization. The desired shop utilization is one that is both realistic and would produce appropriate queue lengths for implementation of a priority scheme. Based on consideration of prior research (both theoretical and empirical) and the results of pilot studies, a moderate level of utilization (85 - 90 %) was set as the target for the shop.

Order Release Rule. Order release rules are those decision rules that control the timing and selection of orders to be released to the shop floor (Lingayat and others, 1995:175). For this study, this variable was held constant to avoid potential interaction effects. Therefore, upon arrival to the shop, orders are immediately released to the shop floor. (This could be interpreted as the shop having no order release rule). This decision was based on a speculation that order release rules introduce an element of consistency by reducing queue lengths and thus reducing the probability that a priority rule would cause a job's relative priority to change.

Due Date Setting Policy. In this study, the overall due dates were set in proportion to the total work of the job. In other words, the total processing time of the job is multiplied by a constant factor and added to the arrival time of the job to determine the exact time that the job is due. This rule is commonly referred to in the literature as the TWK rule for setting due dates (Conway and others, 1967:231), and is considered the "most rational method of assigning due dates" (Blackstone and others, 1982:30).

The method for assigning operational due dates is similar to that for the overall due date. Basically, the processing time of the pending operation is multiplied by the same constant factor as the overall due date, then added to the due date of the previous operation (or the arrival time for the first operation). This is the same method used by Kanet and Hayya (1992).

Due Date Tightness. This variable is closely connected to utilization in that there is a high interdependence between the two variables with respect to due date measures (Elvers and Taube, 1983:88). Therefore, this variable was also held constant at

a moderate level. A moderate level is defined by Philipoom, Malhotra, and Jenson (1993:1117) as the level at which approximately 10% of the jobs are tardy using FCFS as the priority rule.

Shop Size. Baker and Dzielinsky (1960) reported that the number of machines in a shop does not significantly affect the relative performance of scheduling rules. Therefore, this variable was held constant based on the job shop model chosen which will be described later in this chapter.

Arrival Process. This variable was also based on the job shop model chosen. This was not considered a main factor because Elvers (1974) showed that the arrival process is not significant in evaluating the relative effectiveness of priority rules.

Processing Distribution. Similar to the arrival process, this variable was chosen based on the job shop model used. Again, Baker and Dzielinsky (1960) concluded that the processing distribution does not significantly effect the relative performance of scheduling rules.

Now that the main factors and background variables have been identified, it is easier to see the rationale for selecting a two-factor factorial design with repeated measures. Similar to Table 2-2, we can combine the two factors into a 2-by-3 matrix and see the experimental treatments, or situations, that the jobs passing through the job shop will be subjected to. This matrix defines the six different priority rules used in this experiment. This matrix is shown in Table 3-1.

Each cell in the matrix represents one treatment, and each treatment corresponds to a different priority rule. Since we are interested in the performance of the job shop for both levels of consistency and across all three operating characteristics, each priority rule (treatment) will be applied to all jobs that pass through the job shop. This, by definition, makes this experiment a full factorial experiment (Montgomery, 1991:197).

Table 3-1

Matrix Showing the Two Main Experimental Factors

Operating Characteristic	Consistent Version	Inconsistent Version
Arrival-based:	First-in-system, first-served (FISFS)	First-come, first-served (FCFS)
Time-based:	Shortest Total Processing Time (STPT)	Shortest Processing Time (SPT)
Due date-based:	Earliest Job Due Date (EDD)	Earliest Operation Due Date (ODD)

When one treatment is applied to the job shop, its performance is recorded for a set of jobs passing through it. This set of jobs has characteristics unique to those jobs such as arrival times to the shop, processing times, and due dates. If we want to make objective comparisons between the performances of the different priority rules, and be able to attribute those differences to the changes in the priority rules, then the same set of jobs will have to be processed through the shop under the exact same conditions for each priority rule. A repeated measures design is one in which each factor-level combination, or treatment, is applied to each subject (Montgomery, 1991:128). As explained earlier, the treatments in this experiment are the six different priority rules shown in Table 3-1. The subjects in this experiment are the set of jobs passing through the shop. It is desirable that each priority rule be applied to the same set of jobs under the same shop conditions for the reasons described earlier. Therefore, the repeated measures design is a very appropriate design for this experiment.

Description of the Job Shop Model

The job shop model used in this experiment is one that has been used in previous research by Law and Kelton (1982). A graphical depiction of this model is shown in

Figure 3-1. This model was chosen because it possesses characteristics likely to be found in real-world shops. In particular, there are three different part types that are processed by the shop, each with different routings and processing time distributions. There are a different number of machines at the various workcenters, and the utilization rates across workcenters vary. These are all characteristics of real-world shops. By selecting a model that has been used before in simulation research, validation of the model is accomplished by comparing the performance of this model to that of Law and Kelton's model when operated under the same conditions.

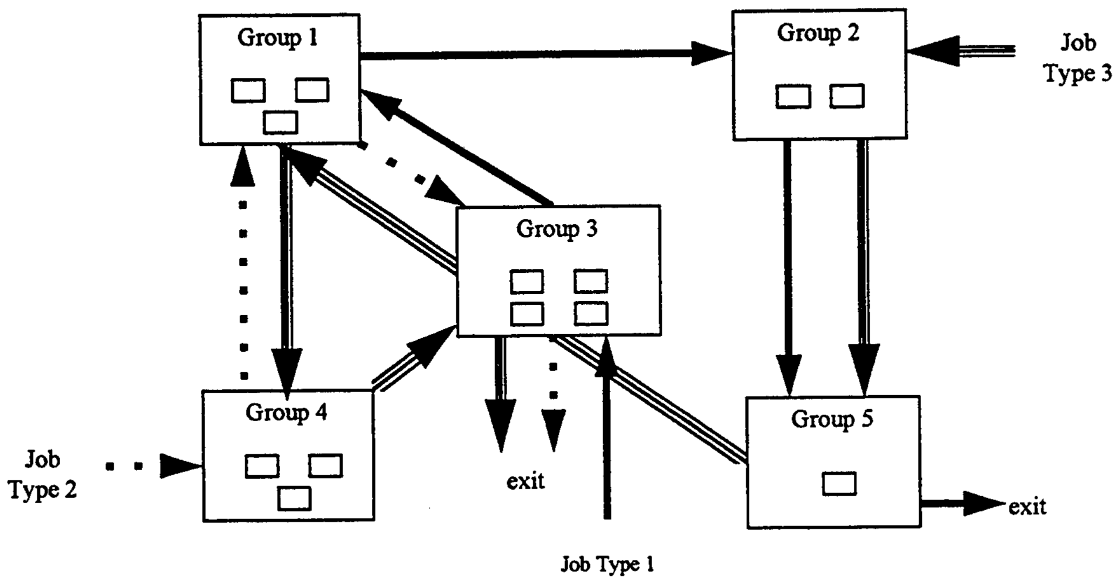


Figure 3-1. Job Shop Model

The shop consists of 5 workcenters or machine groups. The jobs arrive to the shop following a negative exponential distribution. 30% of the jobs arriving to the shop are labeled as Type 1, 50% are Type 2, and 20% are Type 3. The mean interarrival time of 0.268 hours is slightly higher than that used by Law and Kelton who used an interarrival

time of 0.25 hours. When 0.25 was used in this model, some workcenter utilization rates exceeded 95% which generated queues much longer than what might be found in practice or those reported by Law and Kelton. Since this same phenomenon was observed using more than one simulation language, we speculate that it is attributable to differences in random number generators.

The processing times for each part type are drawn from a 2-erlang distribution with means dependent upon the workcenter. The routings and processing times for successive operations of each part type are shown in Table 3-2.

Table 3-2

Part Type Routings and Successive Mean Processing Times

Part Type	Routing	Successive Mean Processing Times (in hours)
1	3, 1, 2, 5	0.50, 0.60, 0.85, 0.50
2	4, 1, 3	1.10, 0.80, 0.75
3	2, 5, 1, 4, 3	1.20, 0.25, 0.70, 0.90, 1.00

As each job arrives to the shop, its actual processing times are immediately calculated and summed. This is done for two reasons. First, the total processing time of each job is required to be able to assign it a priority based on the STPT rule. Second, as mentioned earlier, the total processing time is needed to determine the due date of the job. The due date is calculated by multiplying the sum of the processing times by a factor of 3.75. (This factor is also used to calculate the operational due dates). This value is then added to the arrival time of the job to find the exact time the job is due. As stated earlier, the factor value of 3.75 was selected to cause about 10% of all jobs to be tardy.

Experimental Conditions

Since this is a hypothetical model and does not model any particular real-world shop, it can be considered a non-terminating simulation model. As such, we are interested in the shop's performance under steady-state conditions (Kleijnen, 1987:58). To achieve this, the model was run for one year of simulated time with the first two months discarded to account for the start-up transient effects. The transient period was determined by making pilot runs, and plotting the average total number of jobs waiting in the shop at equal time intervals across the pilot runs. After a moving average was taken, it was apparent that the transient phase ended approximately one month into the simulation. As a conservative measure, this time period was doubled to arrive at a truncation point of two months. This method of determining the transient phase was proposed by Welch (1983).

Thirty-three simulation runs were made for each priority rule listed in Table 3-1. Based on the variances observed in the pilot runs, 33 runs gives us the desired level of confidence to be able to detect a difference of about 20% of the overall mean response. A different random number seed was used for each run within a treatment giving a sample size of 33, and the same set of random number seeds was used for each treatment to ensure the same set of jobs was generated. For each run, data was collected for each of the performance measures listed in the next section.

Performance Measures

As mentioned in Chapter II, the significance of consistency and the potential interaction effect may be different for different performance measures. Therefore, three different performance measures were used in this experiment.

The performance measures collected for this study were chosen to parallel the operating characteristics of the priority rules. For each operating characteristic, a performance measure was chosen such that the corresponding priority rules would tend to

be better than rules of other operating characteristics. For each replication, the mean and variance were collected on each performance measure.

The arrival-based performance measure is based on the average age of the jobs in the shop. Since arrival-based priority rules give priority to the jobs that have been in the shop (or queue) the longest, it would stand to reason that these priority rules would tend to minimize the average age of the jobs in the shop. This performance measure is similar to time in the system. However, that performance measure records an observation as each job leaves the shop. The Average Age measure is a time-persistent statistic in which the age of all jobs still in the shop are averaged and recorded at each simulated event.

The processing time-based performance measure is based on the flow time of each job. Since processing time based rules give priority to the jobs with the shortest processing time(s), it would be expected that these priority rules would tend to minimize the amount of time a job spends in the system. This expectation is also supported by previous research (Ramasesh, 1990:54). The observations of job flow time are recorded as each job leaves the shop.

The due date-based performance measure is based on the amount of time a job is tardy. As a job approaches its due date (either operational or overall), its priority increases. One would expect, then, that the due date-based rules would tend to minimized the amount of time that a job is tardy. The tardiness of a job is defined in this study as the time the job leaves the shop minus the due date of the job. If a job leaves the shop before its due date, it is assigned a tardiness of zero. The observations of tardiness are recorded as each job leaves the shop.

For each replication, a mean value and variance value for each of the above performance measures were taken as the raw data. For example, for each replication, there was a value for the mean flow time (the average flow time of all of the jobs), and a value for the variance of the flow time (variance of flow time of all the jobs). After all

replications were made, 33 observations existed for the mean value and 33 observations for the variance. These observations make up the data that will be evaluated using the procedures outlined in the following section.

Output Analysis

The plan for analysis of the output is the same for each performance mean and variance. As mentioned earlier, this experiment is a full-factorial design with repeated measures. Using this design, we can perform an analysis of variance (ANOVA) to determine which factors are significant, and whether there is significant interaction between the two factors (which is necessary in order to answer investigative questions 2 and 3). If all factors are significant, and there is interaction, we can use a multiple comparison test to evaluate the relative performance of the six priority rules.

Mathematical Model. The general mathematical model for the repeated measures design (Montgomery, 1991:462) is as follows:

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \delta_k + \varepsilon_{ijk}$$

where:

Y_{ijk} = the response of system as the result of the contributions of the independent variables

μ = the overall population mean

τ_i = the effect of factor A at level i

β_j = the effect of factor B at level j

$(\tau\beta)_{ij}$ = the interaction effect between factor A at level i and factor B at level j

δ_k = the effect of the repeated measure

ε_{ijk} = the experimental error

Hypotheses Tested. The repeated measures ANOVA will test the following hypotheses at a level of significance of $\alpha = 0.05$. The results of these tests will provide the bases for answering investigative questions 2 and 3.

1) H_0: all τ_i's = 0	(No significant difference among levels of factor A)
H_a: at least one $\tau_i \neq 0$	(At least one level of factor A is significantly different from another)
2) H_0: all β_j's = 0	(No significant difference among levels of factor B)
H_a: at least one $\beta_j \neq 0$	(At least one level of factor B is significantly different from another)
3) H_0: $(\tau\beta)_{ij} = 0$	(No significant interaction between factor A and factor B)
H_a: $(\tau\beta)_{ij} \neq 0$	(There is significant interaction between factor A and factor B)

Assumptions. There are two basic underlying assumptions associated with a repeated measures ANOVA. First, the ANOVA assumes that the errors (designated as ε in the mathematical model) are normally and independently distributed with a mean of zero. Second, the variance of the error about the mean is equal for all treatments (Montgomery, 1991:59).

When the data has been collected, it is appropriate to look at histograms or probability distribution plots to assess whether or not the data meet the normal distribution assumption. Independence is assured when using the repeated measures design if the replications are randomly sampled. This was accomplished in this experiment by using independent random number seeds for each replication. As for the homogeneity of variance assumption, if each experimental condition is replicated an equal number of times (as is the case in this study), then "non-normality and inequality of variances have little effect on the power of the ANOVA F statistic" (Kleijnen, 1987:291). Therefore, one can

be a little subjective in deciding whether these assumptions are met without compromising the significance of the results.

Expectations

To help facilitate the discussion of the results reported in the next chapter, I will report a couple of a priori expectations based on the literature review and my experience with production systems. I will concentrate my expectations on the relative performance of consistent and inconsistent priority rules within each operating characteristic in terms of their corresponding performance measure.

For the arrival-based rules, I would expect FISFS to have a lower mean flow time than that for FCFS, although I do not expect the difference to be great (it may not even be significant). Under FISFS, the longer a job is in the system, the higher its relative priority will become across all queues. The FCFS rule does not consider how long the job has been in the system, but merely how long it has been in the queue. So, once a job reaches a high relative priority in one queue, it will have to start at the bottom in the next, thus, "slowing" it down.

I would also expect that the FISFS rule would produce a lower variance of flow time than FCFS, although, again, I do not know if the difference will be significant. With FISFS, as a job gets "older" it is pushed through the shop faster, maintaining the flow of jobs through the shop. FCFS has no "expediting" characteristic so some jobs may get through quicker while others may linger.

For the processing time-based rules, I would expect the SPT rule to have a lower mean flow time than the STPT rule. Previous research has shown that the SPT rules is superior when measured in terms of mean flow time. This is because SPT keeps queue lengths to a minimum by processing all the "small" jobs first while leaving the long jobs in the queues longer. STPT, on the other hand, does not attempt to minimize queue lengths,

but instead penalizes jobs with a long processing time at one workcenter by lowering its priority at all workcenters.

With respect to flow time variance, I would expect SPT to have a lower variance as well. Since STPT maintains the priority of a job throughout the system based on the jobs total processing time, jobs with shorter processing times will move through the shop relatively quickly because they have higher priorities and shorter processing times. Conversely, those jobs that have longer processing times will linger, not only because of longer processing times, but because of consistently lower queue priorities as well.

For the due date based rules, I expect that ODD will have a lower mean tardiness than EDD. ODD will keep jobs moving through the shop faster than EDD because ODD has "milestones" associated with it. Since each operation has a due date, a job's priority will increase in each queue as time approaches that operation's due date. This will occur for every operation of the job, which will prevent a job from lingering in any queue for an extended period. EDD does not have the milestones that ODD does. Therefore, EDD could allow a job to remain in a queue until it approaches its overall due date. This could occur while the job is early in the process and still has to pass through its remaining operations Although the job may possess high priority at this point, it must still process through each of its remaining operations. If the job is already close to its due date, the remaining processing time could be enough to make it tardy.

Because ODD incorporates milestones throughout the process, many jobs will have a tardiness of zero, which will, in turn, cause the mean and variance of tardiness to be lower than that of EDD. EDD will have more tardy jobs, and the magnitude of their tardiness will be higher since a job does not have to meet the milestones that it would under ODD. I suspect this will cause a higher mean and variance of tardiness for EDD.

Since the ODD is calculated based on the processing time, ODD will behave similar to SPT by assigning higher priorities to those jobs with shorter processing times.

However, ODD will probably be better than SPT because it will not allow those jobs with longer processing times to remain in the queue for long periods of time because of their operational due date.

Summary

In this Chapter, I described the methodology used to assess the impact of priority consistency on the performance of a job shop. I showed why computer simulation is the most appropriate means for collecting data. I described the main factors of consistency and priority rule operating characteristic, and outlined the background variables and how each was controlled. I proceeded to describe the experimental treatments which correspond to six different priority rules, and described the job shop model to which those priority rules were applied.

I explained how the simulation experiment was carried out, and how the performance of the shop was evaluated. I, then, provided a brief discussion on the plan for output analysis to include the mathematical model, hypotheses tested, and underlying assumptions. Finally, I reported some a priori expectations based on the literature review and my limited production experience. The results of the efforts of this methodology are reported in the next chapter.

IV. Results

Chapter Overview

In this chapter, I will present the results of the experiment described in Chapter III. I will first discuss the means of the three performance measures: flow time, tardiness, and average age of jobs in the shop. For each of these measures, I will show the pattern of behavior and provide statistical support for inferences that can be made regarding these patterns by showing the results of the repeated measures ANOVA. I will then group the mean performances to show which priority rules produced better performance.

After I discuss the means of the performance measures, I will briefly discuss the variances of the same measures. I will show the patterns of behavior, and will explain why no statistical confidence can be applied to the relative variance of the performance measures. I will then look at some other interesting observations regarding the results of the experiment.

Performance Means

In the following sections, I will describe each of the mean performance measures in detail. To describe each mean performance, it is helpful to first look at a graphical representation of the results. From these graphs, we can see not only the possible significance of consistency, but also the interaction effect. For each of the mean performance measures, a repeated measures ANOVA was performed on the data. As stated in the previous chapter, the ANOVA is very robust with respect to the underlying assumptions provided that equal sample sizes are used. Therefore, validation of those assumptions can be somewhat subjective. For all three mean performance measures, the underlying assumptions were sufficiently met to to perform the ANOVA on the data.

Mean Flow Time. A graphical representation of the mean flow time response from each of the six priority rules is shown below in Figure 4-1.

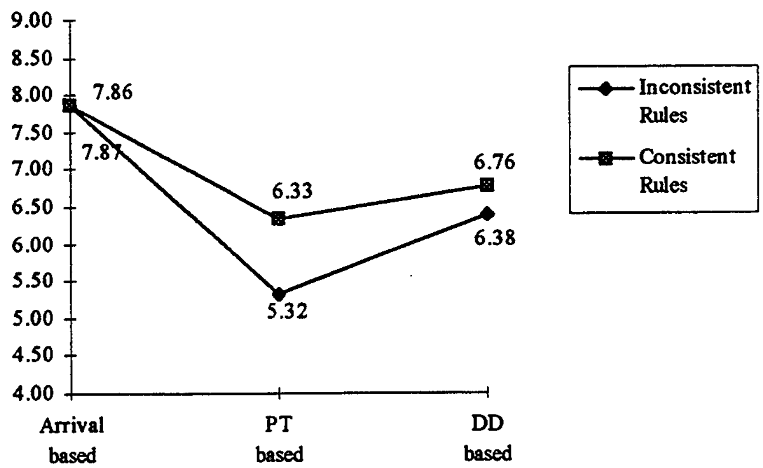


Figure 4-1. Summary of Mean Flow Time

It appears that the inconsistent rules tended to have lower mean flow times than their consistent counterparts with the possible exception of the arrival-based rules. There also seems to be a significant interaction between consistency and the operating characteristics. To confirm this, an ANOVA was performed on the raw data shown in Appendix B. The resulting ANOVA table has been reconstructed in Table 4-1.

Table 4-1

ANOVA Table for Mean Flow Time

Model Term	Source	DF	ANOVA SS	Mean Square	F	F_{crit}
τ =	CONSIST	1	10.34945366	10.34945366	225.53117	3.84
β =	OPCHAR	2	140.88205928	70.44102964	1535.0229	3.00
$(\tau\beta)$ =	CONSIST*OPCHAR	2	8.58934898	4.29467449	93.587836	3.00
δ =	RUNS	32	10.51977525	0.328742977		
	RUNS*CONSIST	32	1.38466768	0.043270865		
ε	RUNS*OPCHAR	64	3.84067872	0.060010605		
	RUNS*OPCHAR*CONSIST	64	2.11693169	0.033077058		
	TOTAL	197	177.6829153	Model MSE =	0.0458892	

The variables listed in the ANOVA table correspond to the factors of the experimental design described in the previous chapter. Specifically, CONSIST represents the consistency factor, OPCHAR represents the operating characteristic factor, and RUNS represents the repeated measure variable which, in this experiment, is the set of jobs being run through the shop. (The label RUNS was used because each run represents a different set of jobs). With a repeated measures design, the interaction between the main factors and the repeated measure are assumed to be negligible, and are included in the error term to further isolate the effect of the main factors (Montgomery, 1991:464).

The ANOVA table clearly shows that, with respect to mean flow time, both the operating characteristic and consistency of a priority rule are significant, and there is a significant interaction effect between the two ($\alpha = 0.05$). We can now apply Duncan's Multiple Range Test on the mean flow times for each priority rule to determine which priority rules perform better than the others. Duncan's Test was selected because it is a relatively powerful test in that it is effective at detecting differences between means when real differences exist. According to Montgomery, when using Duncan's Test, "if the protection level is α, then tests on means have a significance level that is greater than or equal to α" (Montgomery, 1991:75).

From the Duncan's test, the flow time means that are not statistically different are grouped together. This produced four significantly different groups shown in Table 4-2 in order of relative performance with SPT being the best. From that table, it is easily seen that for every operating characteristic except the arrival-based, the inconsistent rule performed better than its consistent counterpart. In addition, the SPT rule performed the best of all six priority rules. Based on the discussion in Chapter III, this is what we would have expected. We can also reaffirm that although "socially just, " FCFS is a poor performer against mean flow time.

Table 4-2

Duncan's Groupings of Mean Flow Time

|				SPT
	|			STPT
	|			ODD
		|		EDD
			|	FISFS
			|	FCFS

Although there is a significant difference between the groups listed above, one must recognize the practical implications of these differences. The approximately 2.5 hour difference in mean flow time between the arrival-based rules and the SPT rule would be a significant improvement, while the approximate 20 minute difference between the ODD rule and the EDD rule may not be. The benefits gained by reducing the mean flow times by 20 minutes may not offset the costs of implementing such a priority rule. Practitioners must consider this before applying these results to their particular situations.

Mean Tardiness. A plot of the tardiness response from the six priority rules is shown in Figure 4-2.

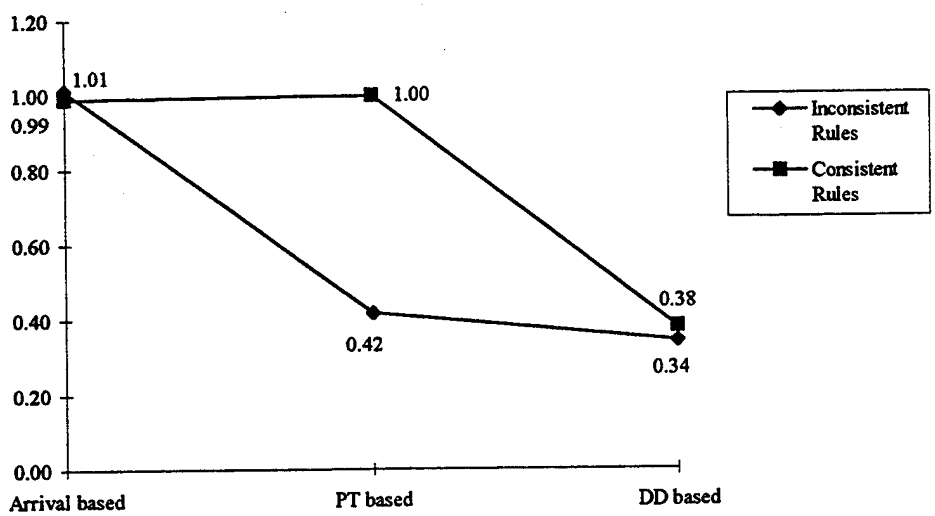


Figure 4-2. Summary of Mean Tardiness

From Figure 4-2, consistency appears to be significant for processing time-based rules, but not necessarily for the arrival-based and due date-based rules, thus indicating the presence of an interaction effect. In addition, it appears that the due date-based rules are among those that produce the better performance as expected. In order to confirm this, we must look at the results of the repeated measures ANOVA performed on the raw data shown in Appendix C. The resulting ANOVA table is shown below in Table 4-3.

Table 4-3

ANOVA Table for Mean Tardiness

Model Terms	Source	DF	ANOVA SS	Mean Square	F	F_{crit}
τ =	CONSIST	1	1.93604667	1.93604667	12.99164718	3.84
β =	OPCHAR	2	13.56189143	6.780945715	45.50285674	3.00
$(\tau\beta)$ =	CONSIST*OPCHAR	2	3.65027834	1.82513917	12.24741351	3.00
δ =	RUNS	32	3.21165398	0.100364187		
	RUNS*CONSIST	32	0.75948949	0.023734047		
ε	RUNS*OPCHAR	64	1.51853857	0.023727165		
	RUNS*OPCHAR*CONSIST	64	1.14173499	0.017839609		
	TOTAL	197	23.8435868	Model MSE =	0.149022418	

From the above table, it is clear that both the consistency and operating characteristic of priority rules are significant, and there is significant interaction between the two, confirming our suspicions from Figure 4-2. Once again, to detect the relative difference between the response of each priority rule, a Duncan's Test was performed on the mean responses. The groupings created by this test are shown in Table 4-4.

Table 4-4

Duncan's Groupings of Mean Tardiness

```
|    ODD
|    EDD
|    SPT
   | FISFS
   | STPT
   | FCFS
```

There is not much we can say about the relative performance of consistent or inconsistent rules with respect to mean tardiness even though the main effect was significant. The only operating characteristic in which there is a significant difference is for the processing time-based rules. In this case, the inconsistent SPT rule performed better than the consistent STPT rule. Unfortunately, we cannot make the same conclusions about the other operating characteristics because there is not a significant difference present. We can, however, confirm the expectations described in Chapter III and conclude that the due date-based rules performed better than the other rules except SPT, where no significant difference was detected.

Mean Age of Jobs in the Shop. The plot for the mean age of the jobs in the system is shown in Figure 4-3.

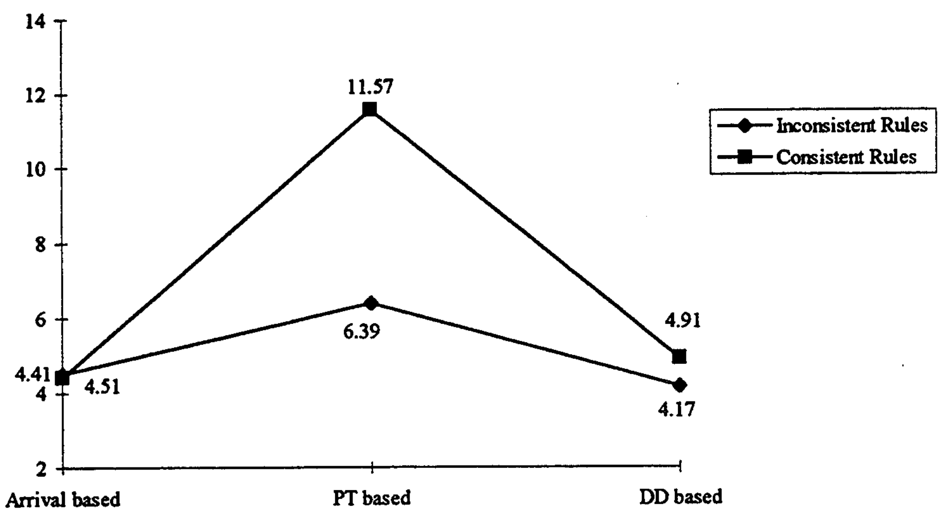


Figure 4-3. Summary of Mean Age of Jobs in Shop

From the above figure, we can see indications of a significant interaction effect. In addition, it appears that the inconsistent priority rules performed better than their

consistent counterparts. Again, an ANOVA will confirm these suspicions. The ANOVA was performed on the data in Appendix D, producing the results shown in Table 4-5.

Table 4-5

ANOVA Table for Mean Age of Jobs in the System

Model Terms	Source	DF	ANOVA SS	Mean Square	F	F_{crit}
$\tau =$	CONSIST	1	185.9355966	185.9355966	229.292693	3.84
$\beta =$	OPCHAR	2	883.02332912	441.5116646	544.4648599	3.00
$(\tau\beta) =$	CONSIST*OPCHAR	2	265.5590752	132.7795376	163.7415229	3.00
$\delta =$	RUNS	32	55.39636609	1.73113644		
	RUNS*CONSIST	32	23.24410256	0.726378205		
ε	RUNS*OPCHAR	64	67.45713288	1.054017701		
	RUNS*OPCHAR*CONSIST	64	39.04426611	0.610066658		
	TOTAL	197	1519.659869	Model MSE =	0.810909385	

The ANOVA table shows that the effect consistency is significant, and there is significant interaction between consistency and the operating characteristics. A Duncan's Multiple Range Test was performed on the treatment means to assess their relative performance. The results of this test are shown below in Table 4-6.

Table 4-6

Duncan's Groupings for Mean Age of Jobs in Shop

|			ODD
|			FISFS
|			FCFS
|			EDD
	|		SPT
		|	STPT

The groupings shown in Table 4-6 do not show anything particularly interesting with regard to the consistency factor except that SPT performed better than STPT. One thing that is interesting is that the due date-based rules performed just as well the arrival

based rules. As mentioned in Chapter III, the arrival-based rules were expected to perform better than the other operating characteristics because as a job gets older, its priority increases. It appears that the due date-based rules are behaving the same way. The reason for this may lie in the method of calculating the due dates.

As described in Chapter III, the operational due date is calculated by multiplying the processing time by a constant factor (3.75), then adding that time to the due date of the previous operation (or arrival time for the first operation). This causes the ODD rule to behave very similar to the SPT rule by processing the shorter jobs first. However, the ODD has one additional benefit in that it will not allow a job with a long processing time to linger like the SPT will. As a job gets older and approaches its operational due date, its relative priority gets higher to the point where it will even surpass the priorities of the jobs with short processing times. This keeps the jobs moving through the shop, and consequently keeps the age of jobs relatively lower.

The reason why the EDD rule performs as well as the arrival-based rules is a little less clear. Since it is based on the total processing time of the jobs, one would expect it to behave similar to STPT with a similar benefit described for ODD of being able to "expedite" the job when it approached its due date. This does not explain, though, why EDD performed as well as the arrival-based rules and notably better than STPT with respect to this measure. The only explanation I can offer is that the processing time-based rules keep a small number of jobs in the shop for an extremely long period of time, which would increase the average age. EDD would not allow this to happen, and thus keeps the average age relatively lower.

Performance Variances

As explained in Chapter III, as each run was made, two observations were recorded for each performance measure: the mean and variance. After the 33 runs were completed, there were two sets of results for each performance measure, and each set consisted of six treatments. The set of treatments that reflected the means of the performance measures were discussed in the previous section. This section will consider the second set of measures that reflect the variances of flow time, tardiness, and average age of jobs still in the shop.

It is important to understand the terminology used here to avoid a highly confusing situation. For each treatment, there exists 33 observations. If we take the arithmetic mean of these 33 observations, we obtain the treatment means. Since we are discussing the variance of the performance measures, the observations within each treatment represent the variance of the response for a particular set of jobs. When we determine the treatment mean, we are determining the mean of the variances of the performance measure.

It is also possible for us to calculate the variance of those 33 observations. This would give us the variance about the treatment means, which is necessarily the variance of the performance variance. It is this variance of the variances that is important in the following discussion.

Just as with the mean performance data, a check for model appropriateness of the assumptions for the repeated measures ANOVA was performed. Histograms showed the data to be fairly normally distributed. However, there was little doubt that the assumption of equal variances was violated. Despite the robust power of the F statistic when equal sample sizes are used, even a strongly subjective approach could not justify validation of this assumption. In most cases, the largest variance was almost ten times bigger than the

smallest. Despite the lack of statistical confidence, it is still possible to discuss the performance variances in terms of what they might suggest about consistency.

When the treatment means (the mean variances) of the three performance measures are plotted, the pattern is notably similar for each measure. Therefore, only the plot for the variance of flow time will be shown here as Figure 4-4. The raw data for the variances of flow time, tardiness, and average age of jobs in the shop are shown in Appendices B, C, and D, respectively. Plots of the tardiness variance and variance of the average age of jobs in the shop are shown in Appendix E.

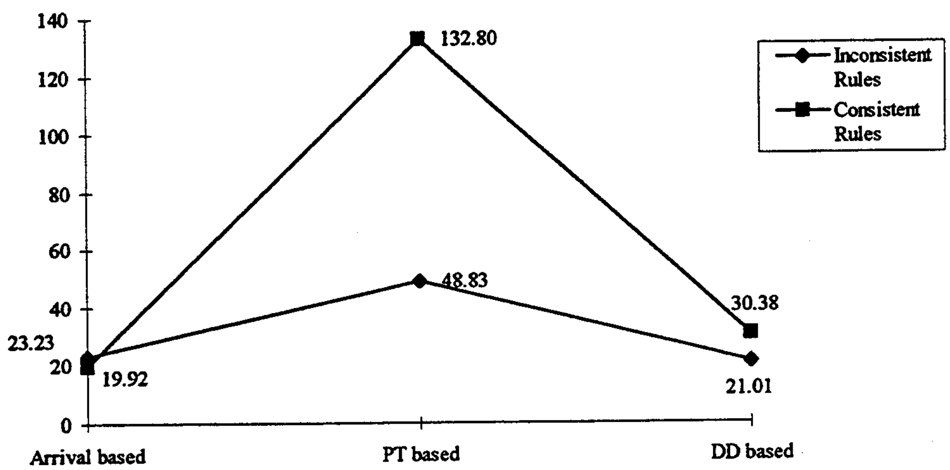


Figure 4-4. Summary of The Flow Time Variance

Similar to the preceding plots, there appears to be a significant interaction between the operating characteristic and consistency. However, it is difficult to say whether the consistent rules are significantly better across all operating characteristics. Once again, though, there is a notable difference between the SPT rule and the STPT rule. The results shown here, although not statistically supported, are consistent with the expectations presented in chapter III.

Analysis by Part Type

Since the job shop model used incorporates three different part types, it may be interesting to look at the results broken down by part type. In the preceding analyses, the biggest differences for all performance measures occurred between the SPT rule and the STPT rule. One may ask why there is such a big difference between the consistent and inconsistent versions of the processing time-based rules that does not appear to be present in the other operating characteristics. By breaking down the flow time performance by part type, we may be able to find an answer to this question.

Figure 4-5 shows the mean flow times for each part type. From this graph, it is easily seen that the difference in performance between SPT and STPT is largely due to the performance of part type 3. Referring back to Table 3-2, the average total processing time of part types 1 and 2 are 2.55 hours and 2.65 hours, respectively. The average total processing time of part type 3 is 4.05. Obviously, under the STPT rule, part type 3 would have a lower priority than part types 1 and 2 in all queues. In addition, type 3 jobs have more operations than type 1 and 2 jobs. Under the STPT rule, these two factors combine to cause the type 3 jobs to remain in the shop quite a bit longer than the other part types.

For the SPT rule, the impact of having more operations probably contributes to the higher mean flow times for type 3 jobs, but the impact of the operational processing times is not so strong because they are fairly comparable across the three part types. Therefore, the difference between the type 3 jobs and the type 1 and 2 jobs is not as great.

This same pattern can be seen in a plot of the variance of flow time shown in Figure 4-6. Again, the combined impact of the longer mean total processing time and more operations cause the variance of flow time for part type 3 to be substantially higher than that of the other two part types under the STPT rule. By contrast, the difference between the variance of type 3 jobs and type 1 and 2 jobs is not so great under SPT since the mean total processing time is probably not a contributor.

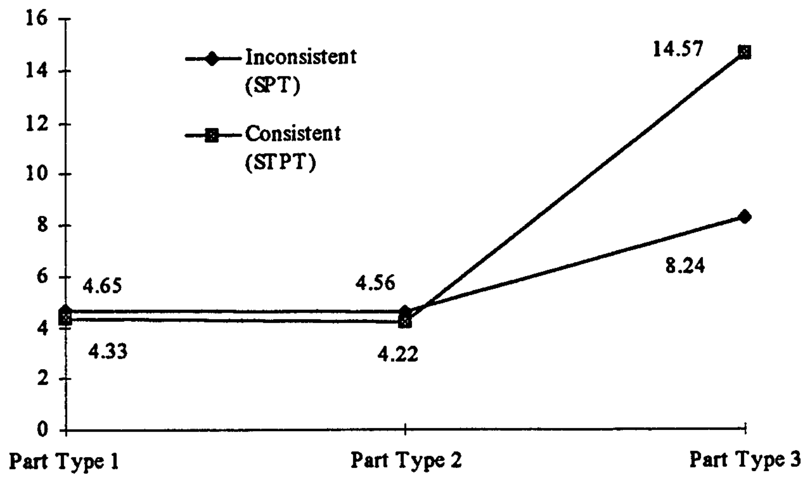


Figure 4-5. Mean Flow Time by Part Type

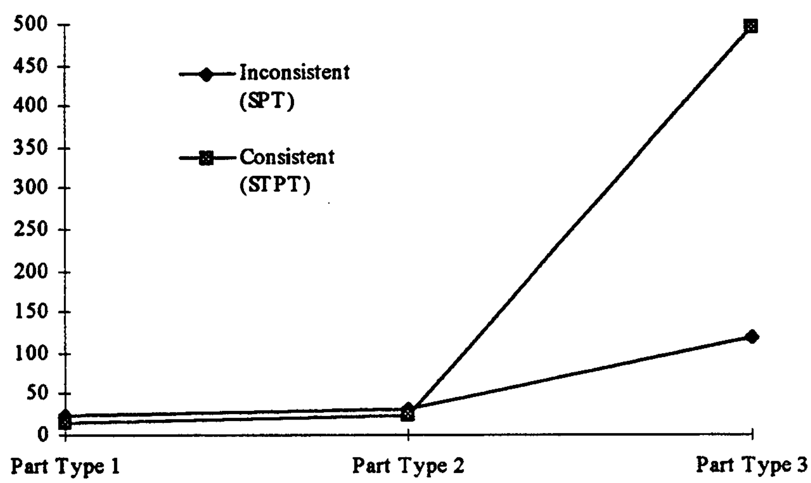


Figure 4-6. Flow Time Variance by Part Type

The difference in flow time performance between SPT and STPT can be attributed to the difference in the total processing time properties of the different part types. As a consistent sequencing rule, STPT is consistently giving priority to job types 1 and 2 over

type 3. As a result, job types 1 and 2 actually do slightly better in terms of both mean and variance of flow time than they do when sequenced according to SPT. Job type 3 absorbs the "cost" of this preferential treatment. Consequently, the STPT rules appears to stratify the performance of the different part types based on their total mean processing times.

For the other operating characteristics, there does not appear to be any particular job characteristic that causes one part type to behave notably different than the others. Therefore, one part type does not skew the data so much that we see a big difference similar to that within the processing time operating characteristic. So while the stratifying effect may be a general characteristic of consistent rules, we do not have results which support such a generalization.

Summary

The purpose of this chapter was to present the results of the simulation experiment described in Chapter III. First, I addressed the mean performance of the shop in terms of the three measures, and supported my findings by using the repeated measures ANOVA. Second, I discussed the relative performance of the shop in terms of the variances, but was unable to assign statistical significance to the observed differences because the data did not meet the basic assumptions of the ANOVA. Then, I attempted to explain why there was a notable difference between the performance of the consistent and inconsistent processing time-based rules, and not between those of the other operating characteristics.

In the next Chapter, I will summarize the results of this experiment by providing answers to the investigative questions in Chapter I. I will offer some suggestions for future research which may provide further insights into the effect of consistency.

V. Conclusions

The main objective of this thesis has been to explore the concept of consistency in decision making as it is applied to production and operations management. In particular, the notion of consistency in job priorities was introduced and operationalized as a new classification of priority rules. This classification, when coupled with a more traditional classification of priority rules, formed the basis for the full-factorial repeated measures design employed in this experiment. Using computer simulation and a hypothetical job shop, performance data was collected and analyzed using a repeated measures ANOVA model. The results of the analysis provide support for conclusions made here with regard to consistency in priority rules.

In this chapter, I will provide a summary of the more interesting conclusions of this experiment. I will restate the investigative questions and attempt to answer each based on the results of this research. Then, I will discuss some recommendations for future research which may further define the impact of consistency in prioritization schemes.

General Conclusions

Four investigative questions were present in Chapter I. The answers to these questions provide the best framework for presenting the conclusions of this experiment. Therefore, each investigative question will be restated, followed by short discussion of the conclusions that can be made based on the results reported in Chapter IV.

> Investigative Question 1: Is there any previous research on the concept of consistency of priority rules? If not, are there any trends in existing studies that make comparisons between consistent and inconsistent priority rules?

Based on the literature review reported in Chapter II, there does not appear to be any previous research that explicitly addresses the notion of consistency as it applies to job

shop production scheduling. However, there are a couple of observations that can be made from the literature when viewed from a broader perspective. First, it appears that the impact of consistency is affected by many intervening variables. Some of these variables might include the existence of an order release rule, and the method of determining due dates (both overall job due dates and operational due dates).

A second observation made from the literature review is that the type of shop modeled seems to be an important factor in determining the relative performance of consistent and inconsistent priority rules. From the tables presented in Chapter II, it appeared that the consistent rules tended to perform better in assembly shops where the coordination of job component activities is desirable.

> Investigative Question 2: Do consistent priority rules generally perform better than inconsistent rules (or vice versa) regardless of the operating characteristic? Do consistent/inconsistent priority rules perform better against certain performance measures?

With respect to flow time, tardiness, and age of the jobs in the shop, the inconsistent priority rules produced significantly lower means than their consistent counter parts, whenever significant differences could be detected. In some situations, a significant difference could not be detected, and in other cases, a big difference existed. We cannot conclude, however, that the inconsistent rules performed the same or better than all consistent rules since some consistent rules did produce lower means than some inconsistent rules, but they were not of the same operating characteristic. In any case, the consistent rules either produced means that were statistically the same or higher than their inconsistent counterparts. It also appeared that the inconsistent priority rules produced lower variances than their inconsistent counter parts for all three performance measures, although no statistical support can be provided for this observation.

When inconsistent priority rules are used, a job may gain a priority advantage in one queue that it may not have had in previous queues. This advantage will allow the job to "pass" other jobs in the shop. Consistent rules eliminate the possibility of these priority advantages by maintaining a job's priority throughout. Thus, the consistent rules tend to hinder the progress of the job through the shop. This explains why the inconsistent rules tended to perform better than their inconsistent counterparts.

In comparison, as reported in Chapter II, Sculli (1987) suggested that rules that tend to coordinate perform better in assembly shops. Consistent rules accomplish this coordination by not allowing job components to gain priority advantages over associated components, or other jobs. For a job shop, this coordination is unnecessary, and as this study suggests, not desireable.

Overall, it appears that these results suggest that local management of prioritization schemes would be more appropriate than a global, or system perspective. The inconsistent rules that produced better performance were all rules that could be calculated using only information available at the particular workcenter. Therefore, inconsistent priority rules should be employed over their consistent counterparts because they are usually easier to implement, and will likely produce the same or better performance.

One domain where this recommendation produces a notable implication is in the use of due date-based rules. In practice, EDD is a more commonly used priority rule than ODD. This research suggests that potential benefits can be gained by switching from EDD to ODD in a job shop environment.

For all three measures, there was not a significant difference between FCFS and FISFS indicating that consistency of priority within the arrival-based rules has little impact, if any. Therefore, FCFS would be the priority rule of choice between the two since it would be the easiest to implement because it only requires information available immediately at the queue in question.

Investigative Question 3: Does the effect of the consistency depend on the operating characteristic of a priority rule?

With respect to mean performance, there was a significant interaction effect between consistency and the operating characteristics for all three performance measures. This interaction also appeared to be present in the variance of performance, although no statistical confidence can be applied to support that conclusion. This interaction effect suggests that both the operating characteristic and consistency need to be considered when implementing prioritization schemes.

It should be noted, however, that the significant interaction effect in all three performance means was largely due to the substantial differences between the STPT rule and the SPT rule. As explained in Chapter IV, this difference was the result of different total mean processing times of the three job types which caused a stratification of performance among the job types. Without the presence of this phenomenon, the interaction effect may have not been significant. The implication of this is that inconsistent priority rules may produce the same or better performance than their consistent counterparts regardless of their operating characteristic when jobs are homogenous.

Investigative Question 4: Are there other interesting observations that can be made based on a comparison of consistent and inconsistent priority rules?

When we looked at the performance of the shop broken down by part type, it appeared that the consistent rules produced lower mean and variance of flow time than the inconsistent rules for two of the part types, while increasing the mean and variance of the third. This was a direct result of the third part type having a mean total processing time of almost twice that of each of the other two part types. This information may be beneficial to those managers who have similar systems, and such a stratification of performance is desirable.

As an example, suppose a shop had to satisfy two different types of orders, customized and generic. Customers who placed the customized orders are considered more important to the shop because they have to wait for their orders, whereas the generic orders are less important because they go directly into some kind of inventory. And suppose that within the customized orders there are two types of jobs that are very similar in total processing time, but quite a bit less than the generic orders. It would be appropriate to adopt the consistent prioritization scheme described above since the performance for the customized orders might be better, even though the performance of the generic orders would be sacrificed. This would not degrade customer service, however, since these generic items are stocked in inventory anyway.

Recommendations for Future Research

There are basically two areas that warrant further investigation with regard to priority consistency. First, as a mentioned in Chapter II, it appears as though the type of shop modeled has a significant impact on the relative performance of consistent and inconsistent priority rules. Different shop types were not considered in this study because that would have created an extremely complex experimental design that would have overshadowed this preliminary investigation into the impact of consistency. However, based on the results of this study and that of Sculli (1987), it is probable that consistent rules would produce better performance in assembly shops where coordination is desirable. However, research incorporating consistency as an experimental factor in assembly shop performance is still needed to confirm these suspicions.

The second suggestion for further study was not directly addressed in this study, but was taken into consideration in Chapter III when discussing the background variables. A comprehensive scheduling policy consists of three components: order release, dispatching, and due date assignment (Wein and Chevalier, 1992:1019). Ahmed and

Fisher (1992) have shown that there is significant interaction among these three components. Therefore, the relative performance of consistent and inconsistent priority rules should be investigated across various methods of order release and due date assignment to further define its impact.

In addition, it is clear that the use of order release rules introduces an element of consistency on the shop floor by holding jobs in a central pool and thus preventing them from superseding previously released jobs. Research comparing various order release rules to various consistent dispatching rules could produce more insights as to the nature and significance of consistency.

Summary

The results of this study have both practical and theoretical implications. From a practical perspective, it is clear that consistency has a significant impact on the performance of production systems. In general, this study suggests that local management of prioritization schemes could produce better performance in systems that can be modeled as job shops. This is contradictory to the "systems approach" frequently espoused in today's management practices. However, this study has shown that a systems approach to prioritization schemes tends to hinder potential benefits gained at the local level, which could significantly improve the performance of the entire system.

From an academic perspective, this research is a first step toward defining a fundamental principle of scheduling with regard to prioritization schemes. The notion of consistency in production management is a construct which may help researchers identify general strategies that can be used to gain improvements in various productive processes.

Appendix A. Definition of Priority Rules

Arrival-based Rules:

First Come, First Serve (FCFS) - Priority is given to the job that arrived in the queue first. This priority rule is sometimes referred to as First In, First Out (FIFO).

First In System, First Serve (FISFS) - Priority is given to the job that arrived in the overall system first. In a flowshop, FISFS is the same as FCFS for the first queue in the system.

Time-based Rules:

Shortest Processing Time (SPT) - Priority is given to the job in the queue with the shortest processing time for the next job.

Shortest Total Processing Time (STPT) - Priority is given to the job in the queue with the shortest overall processing time. The overall processing time is the sum of the processing time of each operation of the job.

Due date-based Rules:

Earliest Due Date (EDD) - Priority is given to the job in the queue with the earliest overall due-date.

Earliest Operation Due Date (ODD) - Priority is given to the job in the queue with the earliest operation due-date.

Appendix B. Flow Time Data

Mean Flow Time Data

Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	8.196	5.471	5.937	7.528	6.259	6.761
2	7.593	5.265	6.210	7.629	6.346	6.398
3	8.684	5.492	6.475	8.182	6.630	7.030
4	7.200	5.317	6.232	7.082	6.130	6.316
5	8.106	5.410	6.366	7.916	6.305	6.665
6	7.785	5.358	6.972	8.532	6.574	7.607
7	6.997	5.114	5.713	7.075	5.956	6.109
8	7.434	5.255	6.576	7.400	6.156	6.464
9	7.687	5.367	6.457	8.155	6.278	6.826
10	8.150	5.125	6.223	7.898	6.038	6.584
11	7.821	5.269	6.561	7.774	6.309	6.572
12	7.949	5.109	5.995	7.569	6.282	6.288
13	8.135	5.325	6.211	8.303	6.751	7.134
14	7.525	5.299	6.180	7.624	6.200	6.883
15	8.142	5.311	6.508	8.108	6.173	6.391
16	7.813	5.388	6.628	8.103	6.336	6.672
17	8.358	5.322	6.798	8.037	6.534	7.172
18	7.877	5.299	6.129	7.876	6.647	6.903
19	7.858	5.386	6.481	8.096	6.270	6.763
20	8.383	5.583	6.696	8.128	6.353	7.100
21	7.846	5.384	6.607	8.086	6.282	6.714
22	7.786	5.526	6.507	8.035	6.373	7.316
23	7.613	5.127	6.261	7.692	6.301	6.606
24	7.539	5.282	6.176	7.782	5.983	6.686
25	8.427	5.523	6.689	8.115	6.445	6.787
26	7.607	5.370	6.350	7.802	6.226	6.646
27	7.678	5.341	6.656	7.668	6.264	6.445
28	8.042	5.223	6.232	7.741	6.307	6.907
29	8.100	5.452	6.541	7.993	6.557	6.632
30	8.066	5.243	6.150	7.780	6.217	6.558
31	8.262	5.305	6.960	8.064	6.433	7.983
32	7.972	5.331	6.567	8.130	6.724	7.031
33	7.093	5.085	5.640	7.558	6.112	6.172

Flow Time Variance Data:

Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	34.286	68.045	16.584	15.464	119.846	29.374
2	24.379	69.340	22.089	26.298	170.769	27.136
3	34.640	56.249	20.783	21.581	164.390	32.020
4	14.139	40.256	18.459	11.379	102.144	24.317
5	21.142	40.358	19.366	16.418	99.613	26.425
6	25.721	51.172	30.493	36.800	224.621	55.663
7	14.118	45.584	14.811	13.829	79.902	23.832
8	18.360	42.524	26.970	14.650	95.697	26.832
9	19.476	57.666	19.003	24.399	112.222	30.540
10	21.643	31.284	18.055	17.221	82.799	27.259
11	21.981	45.852	22.254	16.488	127.252	26.791
12	25.005	26.583	16.677	16.029	115.793	23.524
13	29.121	50.832	19.449	22.957	241.081	34.465
14	18.879	44.375	17.825	17.116	133.998	34.449
15	27.757	52.428	23.751	28.252	102.431	25.046
16	25.106	56.595	28.592	26.938	156.363	28.836
17	25.330	45.608	24.563	17.954	166.429	37.186
18	20.785	41.695	17.641	19.553	188.392	31.696
19	19.112	39.789	21.544	19.154	111.138	27.996
20	30.783	69.577	22.808	20.337	140.638	32.978
21	23.096	59.813	25.313	23.103	114.668	28.450
22	21.211	71.013	21.356	20.664	128.577	35.595
23	18.755	31.158	19.889	17.125	131.419	28.147
24	17.425	40.739	19.357	20.533	101.125	27.963
25	33.210	85.349	24.578	19.701	149.600	28.727
26	18.173	47.332	19.641	17.627	97.013	28.562
27	17.595	44.938	22.132	15.862	103.574	24.512
28	29.057	41.879	20.071	21.151	125.706	36.119
29	23.194	53.487	20.370	19.219	179.514	26.486
30	28.306	39.890	18.135	18.125	112.829	26.405
31	25.718	49.589	26.035	21.464	142.217	51.229
32	20.196	40.345	20.575	16.961	162.351	30.808
33	18.763	30.098	14.160	23.145	98.159	23.187

Appendix C. Tardiness Data

Mean Tardiness Data:

Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	1.375	0.553	0.180	0.766	0.945	0.368
2	0.968	0.443	0.384	1.064	1.097	0.268
3	1.538	0.515	0.312	1.133	1.235	0.429
4	0.574	0.390	0.247	0.539	0.859	0.169
5	1.023	0.422	0.239	0.893	0.905	0.191
6	1.031	0.422	0.743	1.508	1.203	1.129
7	0.539	0.304	0.114	0.614	0.732	0.203
8	0.771	0.392	0.571	0.718	0.870	0.241
9	0.848	0.462	0.261	1.183	0.934	0.420
10	1.040	0.288	0.177	0.939	0.732	0.222
11	0.973	0.394	0.435	0.884	1.007	0.243
12	1.126	0.268	0.155	0.806	0.965	0.157
13	1.241	0.411	0.281	1.211	1.347	0.583
14	0.813	0.383	0.221	0.858	0.939	0.508
15	1.239	0.446	0.500	1.266	0.884	0.179
16	1.070	0.491	0.618	1.263	1.066	0.338
17	1.209	0.423	0.495	1.001	1.216	0.619
18	0.940	0.379	0.175	0.969	1.240	0.437
19	0.896	0.403	0.353	1.060	0.917	0.257
20	1.377	0.561	0.385	1.108	1.006	0.556
21	0.991	0.481	0.493	1.126	0.968	0.263
22	0.933	0.562	0.351	1.082	1.027	0.590
23	0.830	0.297	0.301	0.878	0.984	0.319
24	0.775	0.387	0.272	0.986	0.785	0.301
25	1.380	0.549	0.482	1.059	1.037	0.279
26	0.785	0.447	0.292	0.911	0.879	0.323
27	0.801	0.416	0.391	0.835	0.931	0.144
28	1.236	0.389	0.303	1.017	0.999	0.605
29	1.077	0.471	0.304	1.006	1.130	0.213
30	1.213	0.372	0.247	0.919	0.946	0.235
31	1.165	0.411	0.596	1.089	1.069	1.166
32	0.932	0.377	0.325	0.978	1.245	0.402
33	0.688	0.278	0.085	0.963	0.837	0.126

Variance of Tardiness Data:

Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	14.331	39.299	0.737	3.850	64.846	2.219
2	7.692	44.253	3.318	10.766	110.576	1.596
3	14.389	29.312	1.695	7.456	96.527	3.044
4	2.581	17.491	1.353	2.363	50.746	0.819
5	5.824	15.385	1.112	4.632	44.591	0.810
6	9.065	24.987	6.621	19.007	156.989	19.661
7	2.446	24.440	0.521	3.515	33.699	1.139
8	4.751	19.042	5.922	3.783	44.585	1.335
9	5.153	31.802	1.040	9.958	57.961	2.755
10	5.931	10.925	0.645	5.040	34.716	0.976
11	6.373	22.474	2.700	4.339	69.926	1.250
12	7.910	8.002	0.703	4.169	60.910	0.561
13	11.529	26.966	1.732	8.706	169.865	4.299
14	4.929	21.134	1.019	4.902	79.045	5.605
15	9.565	26.883	3.512	11.410	48.538	0.736
16	7.996	29.394	6.350	10.624	95.653	1.817
17	8.046	20.600	3.237	5.471	100.377	6.440
18	5.621	18.500	0.813	6.686	121.775	3.649
19	5.020	15.623	2.628	5.904	56.079	1.075
20	11.594	39.621	2.066	6.979	82.629	3.337
21	7.148	32.095	4.735	8.294	59.016	1.308
22	5.534	41.296	1.858	6.347	69.490	3.943
23	4.499	11.695	1.706	5.033	74.634	2.027
24	3.995	17.457	1.650	6.910	52.731	1.610
25	13.695	54.290	3.638	6.017	88.264	1.263
26	4.079	22.755	1.629	5.195	45.191	2.571
27	3.816	20.620	2.237	4.119	48.666	0.488
28	10.414	19.457	1.594	6.652	68.693	5.790
29	7.202	26.543	1.601	6.419	115.736	1.079
30	10.666	17.509	1.182	5.329	58.632	0.993
31	8.618	24.714	4.279	7.724	80.907	13.147
32	5.805	16.958	1.832	5.127	94.692	2.617
33	4.931	10.847	0.246	8.844	47.722	0.443

Appendix D. Average Age of Jobs in the Shop Data

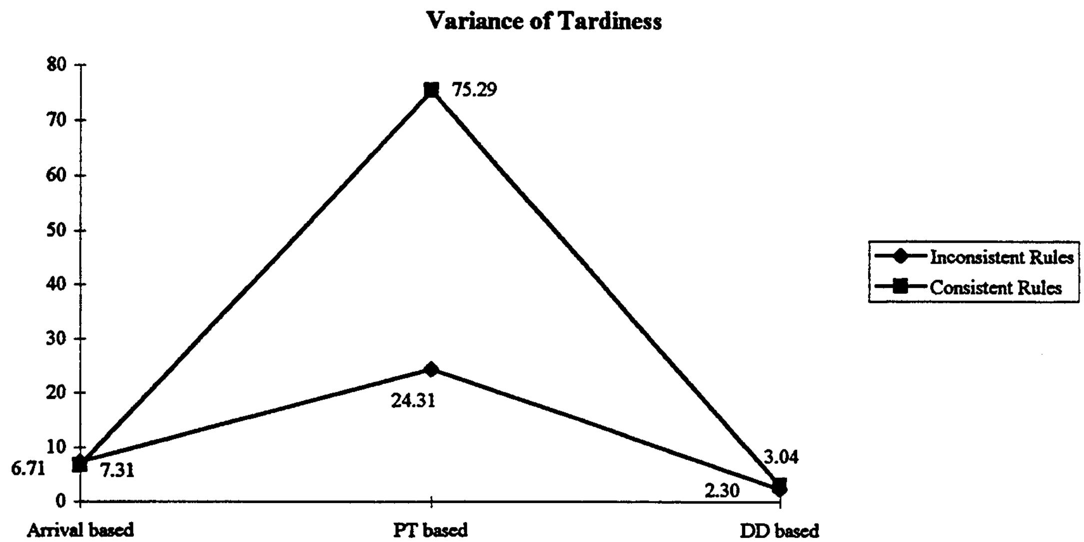
Mean Age of Jobs in Shop Data:

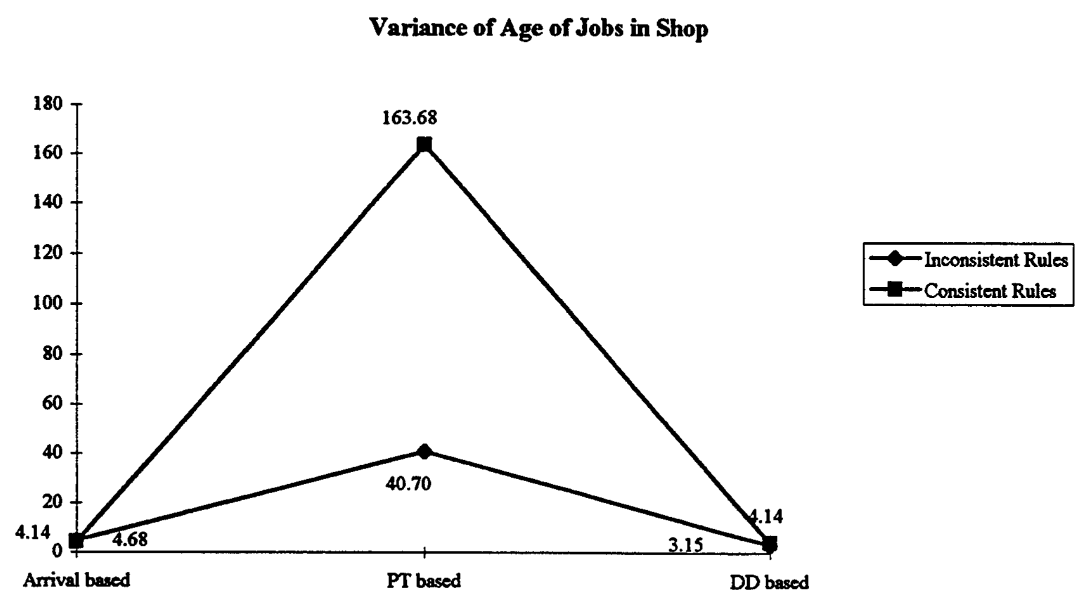
Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	4.850	7.669	3.847	4.225	10.949	4.861
2	4.356	7.778	4.042	4.390	17.678	4.657
3	5.084	6.759	4.194	4.600	13.517	5.091
4	4.072	5.806	4.053	3.898	9.783	4.580
5	4.593	5.935	4.174	4.364	10.232	4.828
6	4.504	6.649	4.632	5.018	16.336	5.573
7	3.935	5.626	3.689	3.917	8.612	4.437
8	4.231	5.942	4.327	4.141	9.495	4.781
9	4.392	7.100	4.201	4.627	10.400	4.917
10	4.694	5.155	4.121	4.393	8.747	4.845
11	4.485	6.118	4.225	4.317	11.022	4.786
12	4.586	4.674	3.919	4.196	10.101	4.479
13	4.608	6.478	4.041	4.679	15.418	5.104
14	4.242	6.104	4.023	4.255	11.764	5.062
15	4.770	6.898	4.233	4.716	10.184	4.680
16	4.483	7.275	4.290	4.650	12.331	4.816
17	4.797	6.292	4.457	4.446	12.942	5.141
18	4.430	5.950	4.019	4.438	13.630	4.975
19	4.435	5.751	4.256	4.517	10.571	4.921
20	4.753	7.454	4.353	4.423	11.424	5.030
21	4.552	7.216	4.357	4.608	10.646	4.922
22	4.509	8.197	4.291	4.563	11.536	5.352
23	4.332	5.028	4.117	4.245	11.489	4.794
24	4.293	5.835	4.042	4.399	10.031	4.834
25	4.965	9.202	4.451	4.579	12.732	4.964
26	4.290	6.208	4.100	4.295	9.506	4.782
27	4.309	6.151	4.339	4.242	9.841	4.668
28	4.648	5.884	4.053	4.328	11.276	5.015
29	4.573	6.956	4.307	4.400	14.494	4.825
30	4.660	5.699	3.964	4.340	10.257	4.750
31	4.829	6.131	4.503	4.535	12.151	5.807
32	4.539	5.872	4.282	4.546	13.054	5.069
33	4.106	5.087	3.689	4.326	9.604	4.533

Variance of Avg. Age of Jobs in the Shop:

Replication	FCFS	SPT	ODD	FISFS	STPT	EDD
1	8.034	70.840	2.366	2.796	110.120	3.957
2	5.299	106.071	3.721	6.460	802.377	3.799
3	7.437	47.515	2.912	4.355	155.550	4.197
4	2.397	22.385	2.452	2.008	70.660	2.871
5	4.025	18.242	2.587	3.122	64.486	2.977
6	5.558	33.609	5.517	9.936	517.154	11.805
7	2.536	42.388	2.000	2.749	45.190	3.348
8	3.542	23.916	4.979	2.695	63.905	3.379
9	3.636	62.663	2.346	5.418	96.540	4.119
10	3.845	13.964	2.250	3.238	51.608	3.143
11	4.248	47.282	3.312	3.051	109.307	3.146
12	5.214	9.522	2.164	2.907	89.815	2.795
13	6.393	38.609	2.826	4.794	480.976	4.784
14	3.515	33.907	2.427	3.378	174.382	5.428
15	5.745	44.764	3.855	6.582	56.096	2.826
16	5.308	57.332	5.428	6.344	195.165	3.690
17	4.809	25.600	3.772	3.273	170.288	5.757
18	3.858	24.507	2.378	3.910	257.306	4.372
19	3.471	15.522	3.324	3.670	78.108	3.208
20	6.723	65.024	3.319	4.139	177.707	4.419
21	4.645	61.735	4.232	5.051	94.043	3.570
22	3.873	71.601	3.018	3.993	115.759	4.452
23	3.471	14.436	2.883	3.370	135.355	3.698
24	3.168	23.514	2.926	4.400	86.591	3.440
25	7.586	139.925	3.884	3.687	214.991	3.362
26	3.330	29.310	2.776	3.358	61.352	3.862
27	3.056	27.504	3.294	2.931	68.717	2.680
28	6.374	32.103	3.048	4.500	114.631	6.172
29	4.378	46.107	2.703	3.893	306.259	2.916
30	5.922	22.080	2.565	3.420	101.383	3.188
31	4.974	33.859	4.033	4.543	124.783	8.934
32	3.944	21.070	2.771	3.158	133.751	3.639
33	3.998	16.047	1.814	5.342	76.955	2.693

Appendix E. Plots of Performance Variance





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Vita

Captain Kenneth W. Bailey is from Tulsa, Oklahoma. He graduated from Oklahoma State University in 1990 with Bachelor of Science degree in Mechanical Engineering. After receiving a regular commission into the United States Air Force as a distinguished graduate of the Reserve Officers Training Corps, he completed the Aircraft/Munitions Maintenance Officers Course (AMMOC) and was assigned to the 5th Bomb Wing (BW) at Minot AFB, North Dakota.

During his tour at Minot AFB, Captain Bailey filled a variety of munitions and aircraft maintenance positions in support of the B-52H aircraft. His munitions experience included Officer in Charge (OIC) of Armament Section, and OIC of Armament Systems Branch. In the spring of 1992, during the creation of Air Combat Command, Captain Bailey became the 23rd Bomb Squadron's first Weapons Flight Commander. In early 1993, Captain Bailey became the 23 BS Sortie Generation Flight Commander managing the sortie production of sixteen B-52H aircraft under the objective wing concept.

In 1994, he was selected to attend the Graduate School of Logistics and Acquisition Management at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio, and graduated in 1995 with a Masters degree in Logistics Management. He was subsequently assigned to Air Mobility Command Headquarters at Scott AFB, Illinois.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1995	Master's Thesis

4. TITLE AND SUBTITLE
THE IMPACT OF PRIORITY CONSISTENCY ON THE PERFORMANCE OF A JOB SHOP

5. FUNDING NUMBERS

6. AUTHOR(S)
Kenneth W. Bailey, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology,
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GLM/LAC/95S-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology,
WPAFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This study introduces the construct of consistency to production/operations management research. As a job passes through a job shop, its priority may or may not remain consistent relative to other jobs in the system. A new classification of priority rules is introduced. Consistent priority rules maintain a jobs priority relative to other jobs throughout the system. Inconsistent priority rules allow a job's relative priority to change as it moves through the system. This study is an initial investigation into the effect of consistency on performance. A simulation experiment was conducted using a full two-factorial repeated measures design with the main factors being consistency and priority rule operating characteristic. Data was collected in terms of flowtime, tardiness, and average age of jobs in the shop. Results showed significant interaction between the operating characteristic and consistency of priority rules for all mean performance measures. In cases where differences between consistent and inconsistent were significant, inconsistent priority rules performed better than their consistent counterparts. This was because the consistent priority rules eliminate priority advantages gained through the use of inconsistent priority rules. This suggests that local management of prioritization schemes will produce better performance than a "systems perspective" in similar job shop environments.

14. SUBJECT TERMS
Production/Operations Management, Scheduling, Dispatching, Priority Rules, Job Shop, Consistency.

15. NUMBER OF PAGES
72

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL